Assessment of Scaphoid Viability With MRI: A Reassessment of Findings on Unenhanced MR Images

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OBJECTIVE. The purpose of this article is to evaluate the accuracy of unenhanced T1-weighted MR images in predicting the vascular status of the proximal pole of the scaphoid in patients with chronic scaphoid fracture nonunions.

MATERIALS AND METHODS. A database search identified 29 patients with chronic scaphoid nonunions who underwent a preoperative MRI examination and intraoperative assessment of scaphoid viability from 2004 to 2009. T1-weighted MR images were evaluated by two musculoskeletal radiologists. If the proximal pole demonstrated diffusely decreased T1-weighted signal (less than or equal to that of skeletal muscle), the patient was placed in a moderate-to-high risk for avascular necrosis (AVN) category. Otherwise, the patient was placed in a viable-to-low risk for AVN category. Scaphoid viability or necrosis was diagnosed intraoperatively depending on whether punctate bleeding was present. After the patients were classified according to the T1-weighted appearance, the appearance on STIR images was recorded.

RESULTS. There were 29 patients (25 male) with a mean age of 21 years. When we compared the MRI results, using only the T1-weighted images, with the surgical findings, unenhanced MRI had a sensitivity, specificity, and accuracy of 55%, 94%, and 79%, respectively, for diagnosing AVN. Increased proximal pole STIR signal was noted with similar frequencies in patients with and without AVN.

CONCLUSION. T1-weighted unenhanced MRI is an acceptable alternative to delayed contrast-enhanced MRI in the preoperative assessment of the vascular status of the proximal pole of the scaphoid in patients with chronic fracture nonunions. STIR images were not beneficial in determining proximal pole viability.

Keywords: MRI, musculoskeletal imaging, wrist and hand

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Chronic fracture nonunions of the scaphoid typically require surgical bone grafting to heal. The vascular status of the proximal pole of the scaphoid is an important factor in determining whether a vascularized or a nonvascularized bone graft is used [1]. Accurate preoperative assessment is important for determining which procedure to perform and for counseling the patient appropriately as to the potential success or failure of the procedure during the process of informed consent.

Numerous early studies within the medical literature reported that unenhanced MRI was accurate for detecting avascular necrosis (AVN) in the proximal pole of the scaphoid in patients with fracture nonunions [2–5]. One of these early studies suggested that, although T1-weighted images were sensitive for detecting AVN in the carpal bones, the findings were not specific, and as a result, those authors advocated using decreased signal intensity on T2-weighted images as a more specific finding for this diagnosis [6].

In 2000, Cerezal et al. [7] reported that the global accuracy of unenhanced MRI in categorizing the vascular status of the proximal scaphoid was only 68%, whereas the global accuracy of gadolinium-enhanced imaging was 83%. They also reported that it was more common to see normal or even increased T2-weighted signal in the proximal pole of the scaphoid in cases of AVN, thus calling into question the prior classification system for categorizing AVN.

A more recent article [8] described the use of MRI in the postoperative evaluation of scaphoid nonunions treated with vascularized bone grafts and included data regarding the preoperative MRI results in these patients, all of whom had surgically confirmed AVN. All 13 patients had decreased

T1-weighted signal; however, six (46%) patients had increased signal in the proximal pole after contrast enhancement, and one patient (8%) had signal similar to the other carpal bones after administration of gadolinium-based contrast medium [8].

Given the varied findings reported in the literature, including the increased T2-weighted signal and paradoxical "enhancement" in some necrotic proximal poles, we decided to reevaluate the accuracy of unenhanced MRI using T1-weighted images for detecting AVN in the proximal pole of the scaphoid in patients with chronic fracture nonunions.

Materials and Methods

This study was approved by the institutional review board at our institution, which waived the requirement for informed consent. A database review identified 37 patients who had undergone surgical repair of a chronic scaphoid fracture nonunion using either a vascularized or a nonvascularized bone graft performed by one of two orthopedic hand surgeons between 2004 and 2009. Entry criteria for this study included a preoperative 1.5-T MRI scan available for review as well as surgical documentation of the intraoperative vascular status of the proximal pole. Twenty-nine patients met the inclusion criteria; seven patients were excluded because no preoperative MRI scan was available for review, and one patient was excluded because no intraoperative assessment of the vascular status of the scaphoid was performed.

The patient's age, sex, location of the fracture within the scaphoid, and the hand involved were recorded. The number of days between the date of the MRI and the date of surgery and the presence of hardware were also recorded. A retrospective review of the images was then performed by two musculoskeletal radiologists, each with a minimum of 7 years of experience in interpreting MRI of the wrist. The reviewers were blinded to the original MRI interpretations and to the operative reports. Solely on the basis of the T1-weighted imaging appearance, the patients were placed into two categories by consensus. If the T1-weighted images showed diffusely decreased T1-weighted signal (equal to or less than that of skeletal muscle) in the proximal pole, they were placed in a moderate-to-high risk category for AVN. To be considered diffusely decreased in signal, the entire proximal pole had to have decreased T1-weighted signal. Patients with normal or heterogeneously decreased signal in the proximal pole were placed into a viable-to-low risk category for AVN. More than 2 months after the patients were classified into viable or AVN categories on the basis of the T1-weighted appearance, the examinations were reviewed again by the same two musculoskeletal radiologists, and the imaging appearance of the proximal pole on the STIR sequences was classified into three categories: moderate-to-marked diffusely increased signal, minimal diffusely increased signal, and increased signal only around the fracture margin with the signal otherwise isointense to the other carpal bones. One patient did not have a STIR sequence, so a T2-weighted fat-suppressed sequence was used.

A final determination of whether AVN was present was based on the operative findings reported by the hand surgeons, with one surgeon performing 28 of the 29 operations. The proximal pole was considered to be viable if any punctate bleeding was apparent on débridement of the fracture margin, curetting of any sclerotic bone, probing the proximal pole, or during creation of a groove for the bone graft. If no bleeding was apparent after extensive débridement, the proximal pole was considered to have AVN.

Results

Of the 29 patients who met the inclusion criteria, 25 were male (mean age, 21 years; range, 11–49 years). There were 11 surgically proven cases of AVN and 18 cases of surgically proven viable proximal poles of the scaphoid, with no difference in mean age between the two groups. Thirteen of the fractures were located in the proximal pole or at the proximal–mid third junction, and 16 fractures were distal to that location. Of the 13 proximal fractures, eight (62%) had AVN of the proximal pole, whereas AVN of the proximal pole was noted in only three (19%) of the 16 fractures located in the mid or distal third of the scaphoid. The mean interval from the date of the MRI to the date of surgery was 54 days (range, 1–307 days) in all patients (59 days for those with AVN and 50 days for those without AVN) (Table 1).

Using the T1-weighted MR images, seven patients were placed into the moderate-to-high risk for AVN category, and 22 patients were placed into the viable-to-low risk for AVN category (Figs. 1–4). When comparing the MR and surgical findings, there were six true-positive results, 17 true-negative results, one false-positive result, and five false-negative results. This resulted in a sensitivity of 55%, a specificity of 94%, a positive predictive value (PPV) of 86%, a negative predictive value (NPV) of 77%, and an accuracy of 79%.

On the STIR or T2-weighted fat-saturated images, there was moderate-to-marked diffusely increased signal in 15 proximal poles, minimally diffusely increased signal in two proximal poles, and increased signal around the fracture margin, but otherwise relatively isointense signal to the other carpal bones, in 12 proximal poles. Six of the patients in this latter group had completely normal T1-weighted signal, with 83% (5/6) of these patients having viable proximal poles at surgery. Diffusely increased STIR signal was present in seven (64%) of 11 patients with AVN and in 10 (56%) of 18 patients without AVN. Postoperative hardware was present in three of the scaphoids, all of which were accurately categorized as either being viable or having AVN.

Discussion

In patients with preserved vascularity to the proximal pole, a nonvascularized bone graft with screw fixation is often sufficient to achieve osseous union. However, if the proximal pole is avascular, a vascularized bone graft, typically utilizing the 1, 2-intercompartmental supraretinacular artery, is considered more likely to achieve an osseous union than is a nonvascularized bone graft [8]. Because the placement of a vascularized bone graft for a scaphoid nonunion is more challenging technically and requires a longer operative time than does the use of nonvascularized graft, knowledge of the vascular status of the proximal pole will allow more appropriate surgical planning, as well as more accurate preoperative counseling.

The optimal MRI technique to diagnose AVN in the proximal pole of the scaphoid has varied over the past two decades. Initial reports utilizing unenhanced MRI to evaluate the proximal pole of the scaphoid were very favorable in terms of diagnosing AVN.

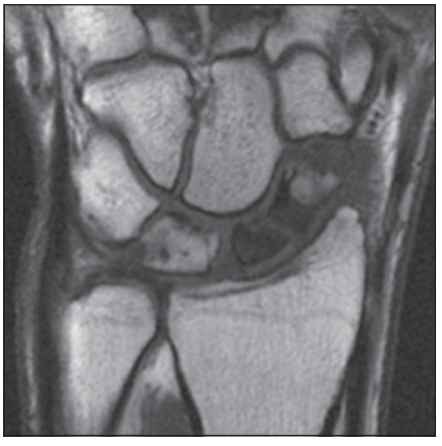

Fig. 1—21-year-old man with avascular necrosis. Image shows true-positive result. T1-weighted coronal image shows diffusely decreased signal within proximal pole. No bleeding was identified at surgery.

TABLE 1: Results of Present Study

Concordant Results	Patient Sex	Patient Age (y)	Hand	Location	T1-Weighted Imaging Results (Risk of Avascular Necrosis)	Operative Findings	Delay Between MRI and Surgery (d)	STIR Results
Yes	Male	21	Left	Proximal pole	Moderate to high	No proximal pole bleeding	136	Isointense to other carpal bones (increased signal at fracture margin)[a]
Yes	Male	20	Left	Proximal pole	Moderate to high	No proximal pole bleeding	93	Isointense to other carpal bones (signal intensity increased at fracture margin)[a]
Yes	Male	19	Right	Proximal to mid pole junction	Moderate to high	No proximal pole bleeding	59	Marked
Yes	Male	16	Right	Mid scaphoid	Moderate to high	No proximal pole bleeding	34	Moderate
Yes	Male	22	Right	Proximal pole	Moderate to high	No proximal pole bleeding	93	Marked
Yes	Male	21	Left	Proximal pole	Moderate to high	No proximal pole bleeding	38	Moderate
No	Male	19	Left	Proximal to mid pole junction	Viable to low	No proximal pole bleeding	62	Moderate
No	Male	23	Left	Proximal pole	Viable to low	No proximal pole bleeding	65	Isointense to other carpal bones (signal intensity increased at fracture margin)
No	Male	39	Left	Mid to distal junction	Viable to low	No proximal pole bleeding	27	Isointense to other carpal bones (signal intensity increased at fracture margin)
No	Male	20	Left	Proximal to mid pole junction	Viable to low	No proximal pole bleeding	29	Marked
No	Male	16	Right	Mid scaphoid	Viable to low	No proximal pole bleeding	16	Moderate[b]
Yes	Male	18	Right	Mid scaphoid	Viable to low	Proximal pole bleeding	49	Isointense to other carpal bones (signal intensity increased at fracture margin)[a]
Yes	Male	30	Left	Proximal pole	Viable to low	Proximal pole bleeding	87	Moderate
Yes	Male	17	Left	Proximal to mid pole junction	Viable to low	Proximal pole bleeding	23	Moderate
Yes	Male	40	Left	Distal pole	Viable to low	Proximal pole bleeding	1	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Male	16	Left	Mid scaphoid	Viable to low	Proximal pole bleeding	10	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Female	15	Left	Mid scaphoid	Viable to low	Proximal pole bleeding	37	Marked
Yes	Male	22	Right	Distal pole	Viable to low	Proximal pole bleeding	45	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Male	18	Left	Mid scaphoid	Viable to low	Proximal pole bleeding	22	Marked
Yes	Male	14	Right	Mid scaphoid	Viable to low	Proximal pole bleeding	58	Marked
Yes	Female	16	Right	Distal pole	Viable to low	Proximal pole bleeding	65	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Male	16	Right	Proximal pole	Viable to low	Proximal pole bleeding	7	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Male	16	Left	Mid scaphoid	Viable to low	Proximal pole bleeding	2	Marked
Yes	Male	18	Left	Mid scaphoid	Viable to low	Proximal pole bleeding	307	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Male	20	Left	Proximal to mid pole junction	Viable to low	Proximal pole bleeding	31	Moderate
Yes	Male	14	Right	Proximal to mid pole junction	Viable to low	Proximal pole bleeding	63	Isointense to other carpal bones (increased signal at fracture margin)
Yes	Female	11	Right	Mid to distal junction	Viable to low	Proximal pole bleeding	42	Moderate
Yes	Female	49	Left	Mid to distal junction	Viable to low	Proximal pole bleeding	24	Minimal
No	Male	23	Right	Mid scaphoid	Moderate to high	Proximal pole bleeding	30	Minimal

[a]Hardware was present.
[b]T2-weighted fat-saturated image was used instead of STIR.

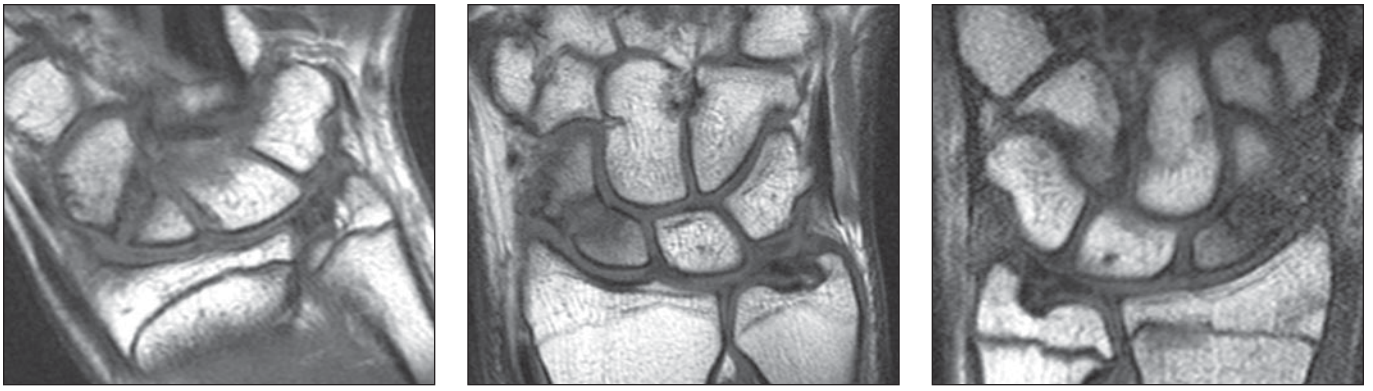

Fig. 2—True-negative results in three patients with varying T1-weighted signals within viable proximal poles. These three proximal poles contain at least some area that has increased T1-weighted signal; signal is equal to fatty marrow.
A, Image of 14-year-old boy shows normal (equivalent to bone marrow) T1-weighted signal.
B, Image of 18-year-old man shows mildly heterogeneous T1-weighted signal.
C, Image of 17-year-old boy shows markedly heterogeneous T1-weighted signal.

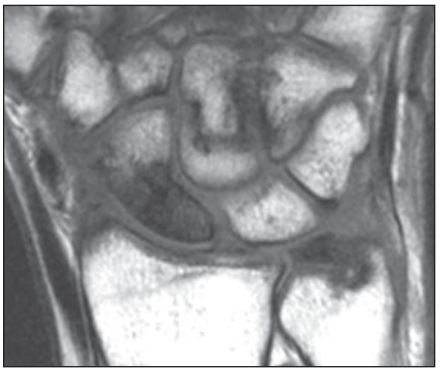

Fig. 3—23-year-old man with false-positive result. T1-weighted coronal image shows diffusely decreased signal in proximal pole. At surgery, punctate bleeding was identified.

Trumble and Irving [2] reported that decreased T1-weighted and T2-weighted signal involving more than 50% of the proximal pole of the scaphoid correctly indicated AVN in all six of their cases. Morgan et al. [5] correctly diagnosed AVN in 13 of 14 patients utilizing the same criteria. Others have reported that decreased T1-weighted signal alone was accurate in diagnosing AVN in the proximal pole of the scaphoid [3, 4]. In addition, decreased T2-weighted signal was present in only 50% of the patients with AVN in one of these studies [3].

Because of these and other published results, an MRI classification system to determine bone viability was devised on the basis of the T1-weighted and T2-weighted signal. The bone was considered viable if the T1-weighted and T2-weighted signals were normal, ischemic if decreased T1-weighted and increased T2-weighted signals were evident, and necrotic if decreased T1-weighted and T2-weighted signals were present. The use of gadolinium-based contrast agent to categorize the vascular status of the proximal pole of the scaphoid was later described, with homogeneous enhancement representing viable bone, inhomogeneous enhancement representing coexisting AVN and viable bone, and the absence of enhancement representing necrosis [9].

These classification systems remained until Cerezal et al. [7] directly compared the accuracy of unenhanced and contrast-enhanced MRI to intraoperative findings for evaluating proximal pole AVN in 30 patients. The patients were divided into four groups on the basis of the T1-weighted and T2-weighted fat-suppressed imaging appearance. On unenhanced imaging, patients in group 1 (normal-to-minimal ischemia) had signal in the proximal pole isointense to normal carpal bones on T1-weighted and T2-weighted fat-suppressed images. Those in group 2 (moderate ischemia) had slightly low signal in the proximal pole on T1-weighted images and homogeneously increased signal on T2-weighted fat-suppressed images. Patients in group 3 (severe ischemia) had variably low signal on T1-weighted images and heterogeneous signal on T2-weighted fat-suppressed images. Those with necrosis or AVN (group 4) had low signal on T1-weighted and homogeneously decreased signal on T2-weighted fat-suppressed images. Using gadolinium-enhanced T1-weighted fat-suppressed imaging, patients in group 1 had marked and homogeneous enhancement involving more than 80% of the volume of the proximal pole. Patients in groups 2, 3, and 4 showed enhancement in 50–80%, 20–50%, and 0–20% of the proximal pole, respectively. Intraoperative vascularity was classified as

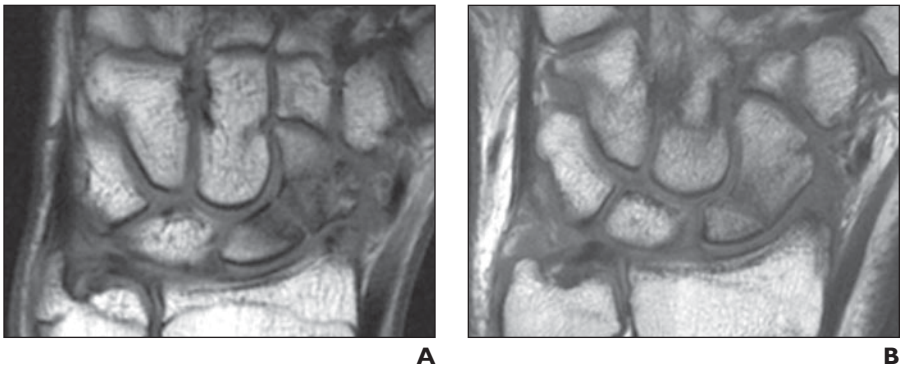

Fig. 4—False-negative results in two patients.
A, T1-weighted signal within proximal pole isointense to normal fatty marrow resulted in classifying proximal pole as viable in 19-year-old man. However, no punctate bleeding was identified at surgery.
B, Coronal image of 23-year-old man with avascular necrosis at surgery shows heterogeneously decreased T1-weighted signal within proximal pole.

good (group 1), fair (group 2), poor (group 3), and absent (group 4). The accuracy of categorizing patients into each of these four groups, in an attempt to determine the degree of ischemia and not just determine whether the proximal fragment was ischemic or viable, was 68% for unenhanced imaging and 83% for contrast-enhanced MRI. As a result, those authors concluded that unenhanced MRI findings were not reliable for assessing the degree of ischemia or viability of the proximal fragment [7].

When the patients were placed into only two groups—those with viable proximal poles (groups 1–3) or AVN (group 4)—the sensitivity, specificity, and accuracy were 71%, 74%, and 73%, respectively, for unenhanced MRI and 86%, 96%, and 93%, respectively, for contrast-enhanced MRI. The PPV and NPV for unenhanced MRI were 45% and 89%, respectively, whereas the PPV and NPV for enhanced MRI were 86% and 96%, respectively. Cerezal et al. [7] stated that, "although inferior to gadolinium-enhanced MR imaging, unenhanced MR imaging enabled us to distinguish between potentially viable bone and nonviable bone." Even so, the use of enhanced imaging for determining the vascular status of the proximal pole gained popularity.

A more recent article [8] described the preoperative imaging appearance of the proximal pole of the scaphoid in 13 patients with surgically confirmed AVN. All 13 patients had decreased T1-weighted signal; however, six patients (46%) had increased T1-weighted fat-suppressed signal in the proximal pole after administration of contrast medium. Three (23%) of the patients exhibited "marked" increases in T1-weighted fat-suppressed signal after administration of contrast medium. The authors commented that "the exact cause for this apparent increased contrast pattern remains unknown" [8].

Several factors might explain this counterintuitive finding of necrotic bone apparently enhancing. One explanation is the in-growth of viable fibrous mesenchymal tissue into necrotic bone [10]. Another is the diffusion of contrast agent throughout the soft tissues, including bone, on conventional contrast-enhanced MRI. This occurs because most conventional contrast-enhanced MR images are obtained in the late vascular phase, 4–9 minutes after contrast administration. Contrast-enhanced images obtained in this phase may appear to show enhancement and, as a result, may be less informative about the vascular status [11]. One animal study also reported variable appearances within bone after administration of contrast medium, with some "normal" femoral heads apparently not enhancing, whereas avascular femoral heads typically showed inhomogeneous enhancement [12]. In total, these studies describing apparent enhancement in pathologically confirmed areas of osteonecrosis raise the possibility that routine conventional contrast-enhanced T1-weighted imaging may be unreliable in determining the vascular status of the proximal pole of the scaphoid in patients with fracture nonunions.

TABLE 2: Comparison With Other Recent Studies Addressing MRI Evaluation of the Proximal Pole of the Scaphoid

Study	Sensitivity (%)	Specificity (%)	Accuracy (%)	PPV (%)	NPV (%)
Cerezal et al. [7][a]					
Unenhanced, low T1/ T2-weighted image	71	74	73	45	89
Enhanced image	86	96	93	86	96
Anderson et al. [8]					
Low T1-weighted image	100	NA	NA	NA	NA
Enhanced image	54	NA	NA	NA	NA
Present study	55	94	79	86	77

Note— PPV = positive predictive value, NPV = negative predictive value, NA = not applicable.
[a]For the study by Cerezal et al., images were analyzed whether or not avascular necrosis was present.

We postulated that, by utilizing a less stringent criterion of requiring only diffusely decreased T1-weighted signal to diagnose AVN, more proximal poles would be classified as having AVN than if one required both decreased T1-weighted and decreased STIR T2-weighted fat-suppressed signals to make that diagnosis. In fact, there were no more than two proximal poles that exhibited diffusely decreased T1-weighted signal and showed probable isointense signal on STIR images that would have been characterized as having AVN if we had used the same criteria as Cerezal et al. [7]. This confirmed our hypothesis.

Thus, using our criteria, we expected to find more false-positive results and fewer false-negative results than Cerezal et al. [7], when using unenhanced imaging, resulting in a lower specificity and a higher sensitivity. However, we actually found the opposite, with more false-negative results and only one false-positive result.

When further comparing our results to those reported by Cerezal et al. [7] using enhanced imaging, our specificity and PPV are similar; however, our sensitivity, NPV, and accuracy are less. This is due entirely to having more false-negative results. Two of these false-negative results might be explained by a delay between MRI and surgery of over 2 months. Another false-negative result we reported might be accounted for by mummified fat, which was discussed by Vande Berg et al. [13]. Another possible explanation for our higher false-negative rate could be the fact that the criteria used by Cerezal et al. to diagnose AVN in the proximal pole on enhanced images was enhancement of less than 20% of the proximal pole. If Cerezal et al. had required the complete absence of enhancement to diagnose AVN, the possibility exists that more proximal poles would have been classified as being viable when, in fact, they were avascular, leading to more false-negative results. Although this last comment is speculation on our part, we think that attempting to assign percentages is difficult and extremely arbitrary. As a result, we propose using homogeneously decreased T1-weighted signal throughout the entire proximal pole as a more useful sign of AVN and one that is easier to replicate.

Compared with the findings of Anderson et al. [8], our results are very favorable. Those authors reported that seven of 13 proximal poles with surgically confirmed AVN had decreased or isointense signal and six of 13 proximal poles had increased signal on T1-weighted fat-suppressed images after administration of contrast medium, resulting in a sensitivity of 54%. All of the proximal poles in that article had decreased T1-weighted signal, resulting in a sensitivity of 100% [8] (Table 2). We also confirmed what has been previously published regarding the low sensitivity of STIR or T2-weighted fat-suppressed images in diagnosing AVN in the proximal pole of the scaphoid [7, 8] (Figs. 5 and 6).

Other factors, including cost and risk, need to be considered in any imaging evaluation. At our institution, the total charge for a contrast-enhanced upper extremity MRI examination is 20% higher than the cost of

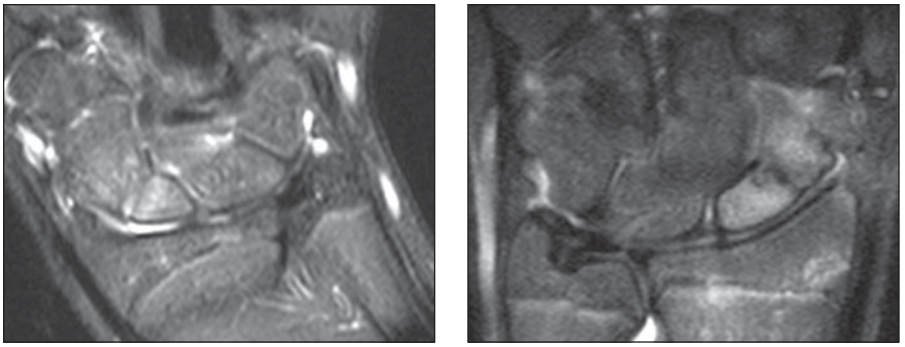

Fig. 5—Varying signals within proximal pole on STIR coronal images of two patients with punctate bleeding present at time of surgery.
A, Image of 14-year-old boy shows isointense signal in proximal pole to other carpal bones with increased signal at fracture margin.
B, Image of 17-year-old boy shows diffusely increased signal.

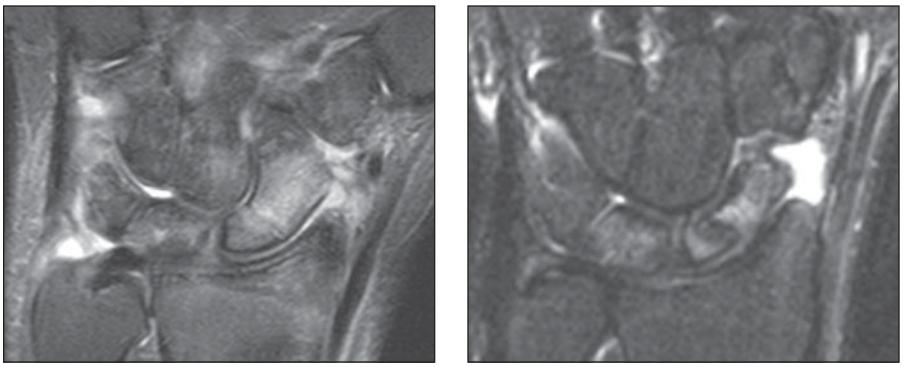

Fig. 6—Coronal STIR images of two patients with proximal pole avascular necrosis.
A, Image of 23-year-old man shows isointense signal in proximal pole to other carpal bones with increased signal at fracture margin.
B, Image of 21-year-old man shows diffusely increased STIR signal.

an unenhanced examination. In addition, the performance of the contrast examination requires approximately 15 additional minutes of MRI table time. Finally, the injection of gadolinium-based contrast medium carries some risk, although it is extremely small in this patient population, which typically is young and otherwise healthy.

Limitations of our study include its retrospective nature as well as the fact that we were unable to blind our surgeons to the MRI results preoperatively because they used the MRI findings for operative planning and for counseling the patients. Additionally, our sample size was small, though commensurate with most of the other studies addressing this topic. There was also a delay of over 2 months between the date of the MRI and the date of surgery for nine patients, including two patients who had proximal poles that were considered viable on MRI but were found to have AVN at the time of surgery. We also relied on the operative findings as our reference standard with which to compare the imaging findings. Perhaps most important, we lacked a direct comparison with contrast-enhanced images on all of our patients.

The role of routine delayed contrast-enhanced imaging is uncertain given the questions that remain regarding apparent enhancement in pathologically proven avascular bone as well as the difficulty in attempting to assign percentages to the enhancing areas in everyday clinical practice. Our criterion of requiring diffusely decreased T1-weighted signal, equal to or less than that of skeletal muscle, to diagnose AVN in the proximal pole of the scaphoid is simpler and less complex than other previously proposed criteria. Given our reported high specificity, high PPV, and moderately high accuracy, T1-weighted images can be an acceptable alternative to enhanced MRI in the preoperative assessment of the vascular status of the proximal pole of the scaphoid in patients with chronic fracture nonunions. In addition, we confirmed that neither STIR nor T2-weighted fat-suppressed sequences are helpful in determining the vascular status of the proximal poles in these patients.

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